Genesis Trajectory Design

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Extended Abstract

Introduction

The Genesis mission will launch in 2001, sending the spacecraft into a halo orbit about the Sun-Earth L1 point to collect and return solar wind samples to the Earth for analysis in 2003. One of the most constraining aspects of the mission design is the requirement to return to the designated landing site (the Utah Test and Training Range, UTTR) during daylight hours. The ongoing mission design has led the development of a family of solutions that characterize a broad range of conditions at Earth entry. Characterizing this family provides insight into the possible existence of additional trajectories while also helping to narrow the search space by indicating where additional solutions are unlikely to exist; this contributes to a more efficient utilization of mission design resources.

Trajectory Design Processes

During the proposal phase of the mission, a trajectory was designed that returns close to the desired region[1]. One of the most appealing aspects of that solution is that the entire trajectory, from launch through entry, requires only a single, small deterministic maneuver, at the halo orbit insertion point (HOI). No deterministic maneuvers are required along the halo orbit, along the return trajectory, or between the halo orbit and return phases. This trajectory, however, does not satisfy all of the current mission design constraints. Ongoing efforts aimed at refining the trajectory in the presence of additional mission requirements have resulted in a new reference solution that satisfies all current mission design constraints while providing significant insight into the solution space.

The halo orbit and return portions of the trajectories that arrive at UTTR impact are presented in Figure 1, relative to Sun-Earth rotating coordinates. (Each trajectory was constructed to connect to the same launch trajectory, using different maneuvers at the insertion to the halo orbit.) The solution identified as Case 2 is the current nominal Genesis trajectory; it satisfies all current mission design constraints. Each of these solutions was computed using a numerical differential corrections scheme that constrains only the initial (HOI) and final (entry) conditions[2]. A key issue in this strategy is that the omission of constraints on the size of the halo orbit allows the halo orbit and return trajectory to respond to a variety of entry constraints. The flexibility that this strategy provides to the trajectory permits the development of the family of candidate trajectories.

Trajectory Characteristics

Each orbit begins at the same HOI position and time. At the other end of the trajectories, each solution impacts at the desired UTTR target point (using a preliminary model for the atmospheric effects). However, the trajectories differ significantly between the HOI and entry points, diverging immediately following the insertion maneuver. Several important characteristics of the three cases are included in Table 1. (PMD in Table 1 refers to Earth fixed, prime meridian of date coordinates.)

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	Case 1	Case 2	Case 3
Line type in Fig 1	Dotted	Solid	Dashed
Halo orbit y-amplitude	860,000 km	813,000 km	720,000 km
Times of lunar flybys on return leg (2003) (GMT)	April 03 00:27 April 14 02:56	April 04 18:13 April 12 11:20	April 11 13:57
S/C-Moon closest approach distance (km)	405,000 km 425,000 km	345,000 km 350,000 km	260,000 km
Entry date (2003) (MDT)	Aug 13 10:54	Aug 16 10:46	Aug 19 16:34
Entry inclination (EME2000)	42 deg	52 deg	71 deg
Entry right ascension (Earth fixed, PMD)	42.1 deg	46.5 deg	50.6 deg
Entry declination (Earth fixed, PMD)	231.3 deg	233.1 deg	239.0 deg
Entry flight path azimuth (EME2000)	93.7 deg	117.7 deg	150.1 deg
Entry velocity	11.0474 km/s	11.0463 km/s	11.0456 km/s

Table 1. Characteristics of Representative Trajectories

Critical Design Parameters

Despite the original design criteria to avoid the Moon, one of the most important parameters that has been identified in the trajectory design is the distant lunar passage on the first portion of the return leg (April 2003). The importance of the Moon to the return trajectory has been recognized since the early design phase of the mission. Trajectories that are not significantly influenced by the Moon during this portion of their departure from the halo orbit do not return to the Earth. Alternatively, trajectories that experience too large of a gravity assist from the Moon also do not return toward the Earth with the required conditions. Establishing the range of trajectories that might be available and understanding how those characteristics relate to Genesis mission design constraints has been one of the most challenging aspects of the mission design process.

Figure 2 is a plot of the early portion of the return trajectory, from April 1, 2003 through April 20, 2003. Time ticks at three-day intervals on the figure identify the location of the Moon as the trajectories pass near the lunar orbit. The times of lunar closest approach during this interval are included in Table 1, along with the closest approach distances. Although the lunar flyby distances are more than 250,000 km in all cases, these distant encounters are critical to establishing the proper timing and conditions for the desired entry characteristics.

Table 1 includes the closest approach times for these distant encounters. However, the cumulative effect of the Moon's influence over an extended period of time is an even more important factor to the shape and phasing of the trajectory. Figure 3 is a plot of the distance between the Moon and the trajectory in the early phase of the return trajectory. The sustained lunar influence that is evident in Case 3 has a quantitatively different effect on the trajectory than the shorter, more distant influences experienced by the other two cases. The Case 3 trajectory gets within 65% closer to the Moon than Case 1. And, perhaps more importantly, Case 3 stays at a distance of about 250,000 km from the Moon for more than 8 days, while the other two cases experience only shorter, more distant flybys that have less effects on the trajectories.

One result of this increased lunar influence on the trajectory in Case 3 is that the loop on the anti-Sun side (the "L2 loop") is significantly larger than the L2 loops for trajectories that experienced a smaller lunar effect. The lunar effect pushes the trajectory further away from the Earth. This results in a later Earth return date for Case 3 than for the other two trajectories eventhough C3 is the first of the three to pass the Earth on the return.

Summary

The influence of the Moon along the return leg of the trajectory is critical to returning the Genesis spacecraft to the Earth. However, the phasing of the trajectory relative to the location of the Moon is a key factor in determining the global characteristics of the trajectory. Analyzing this phasing has given the mission design team significant insight into why the trajectory behaves in particular ways and has benefited the design of new trajectories to accommodate new mission constraints.

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References

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[2] R.S. Wilson, "Trajectory Design in the Sun-Earth-Moon Four Body Problem," Ph.D. Thesis, Purdue University, December 1998.

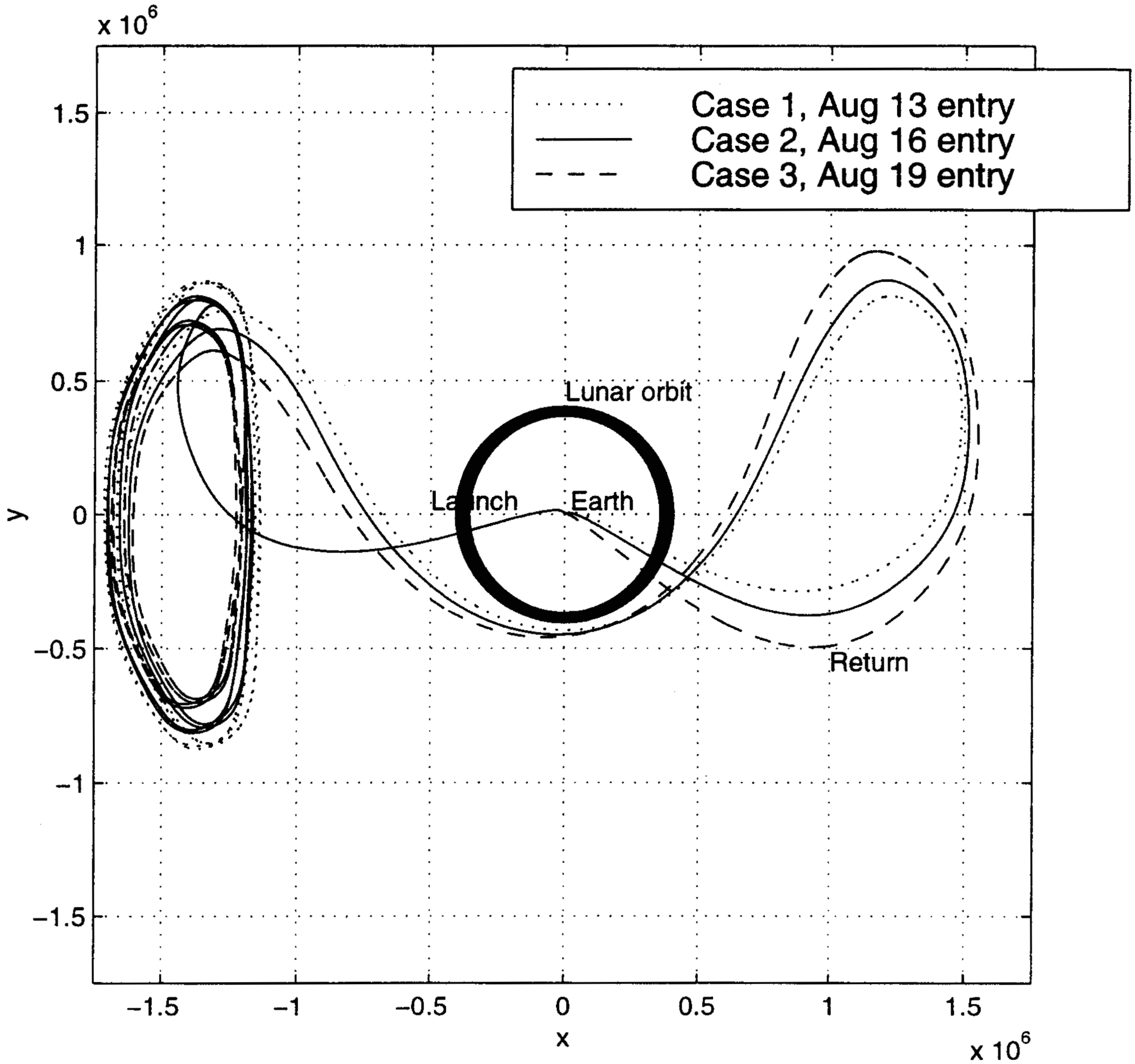

Figure 1. Three halo/returns that arrive at UTTR.

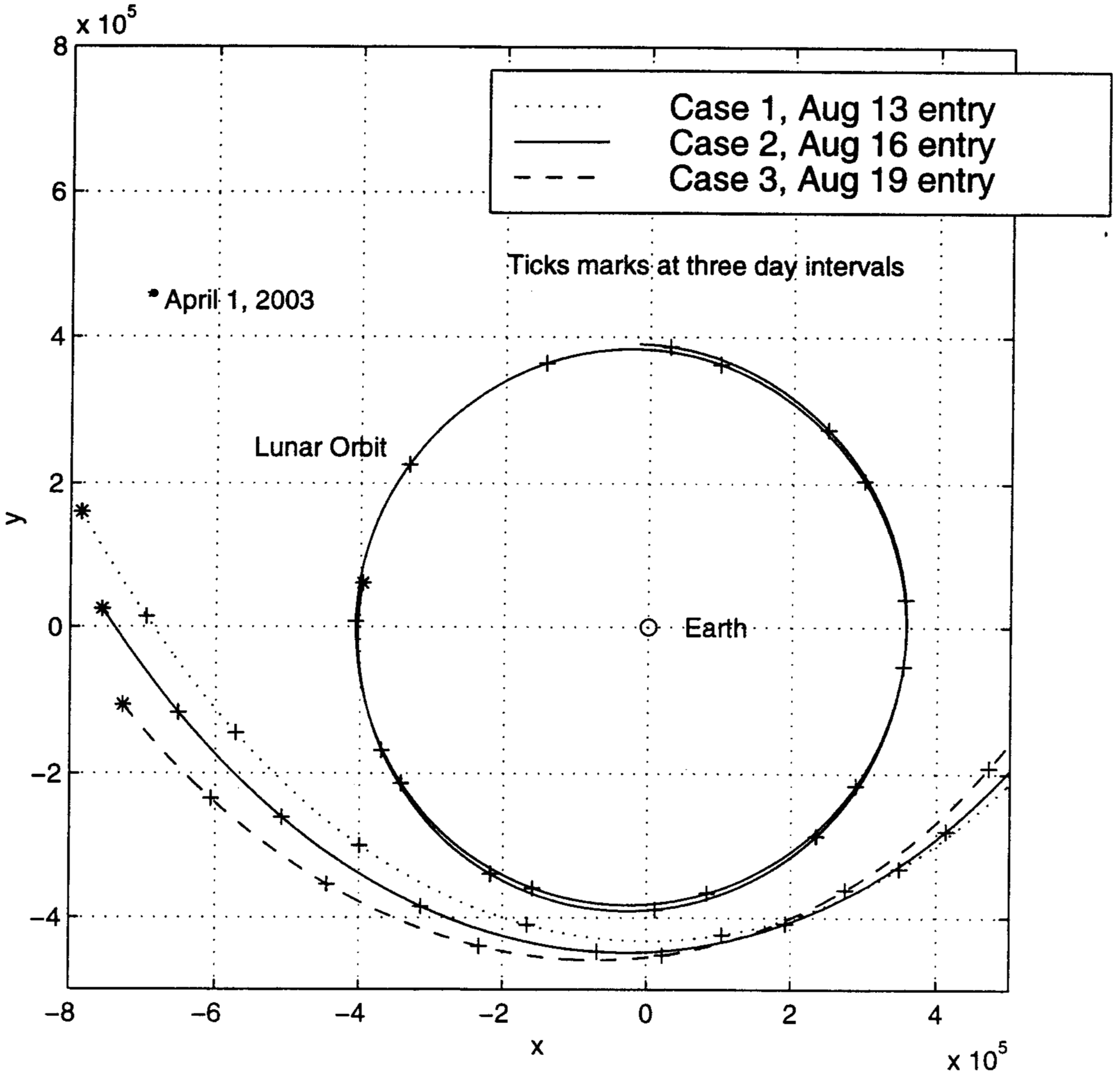

Figure 2: Phasing of lunar and spacecraft Trajectories.

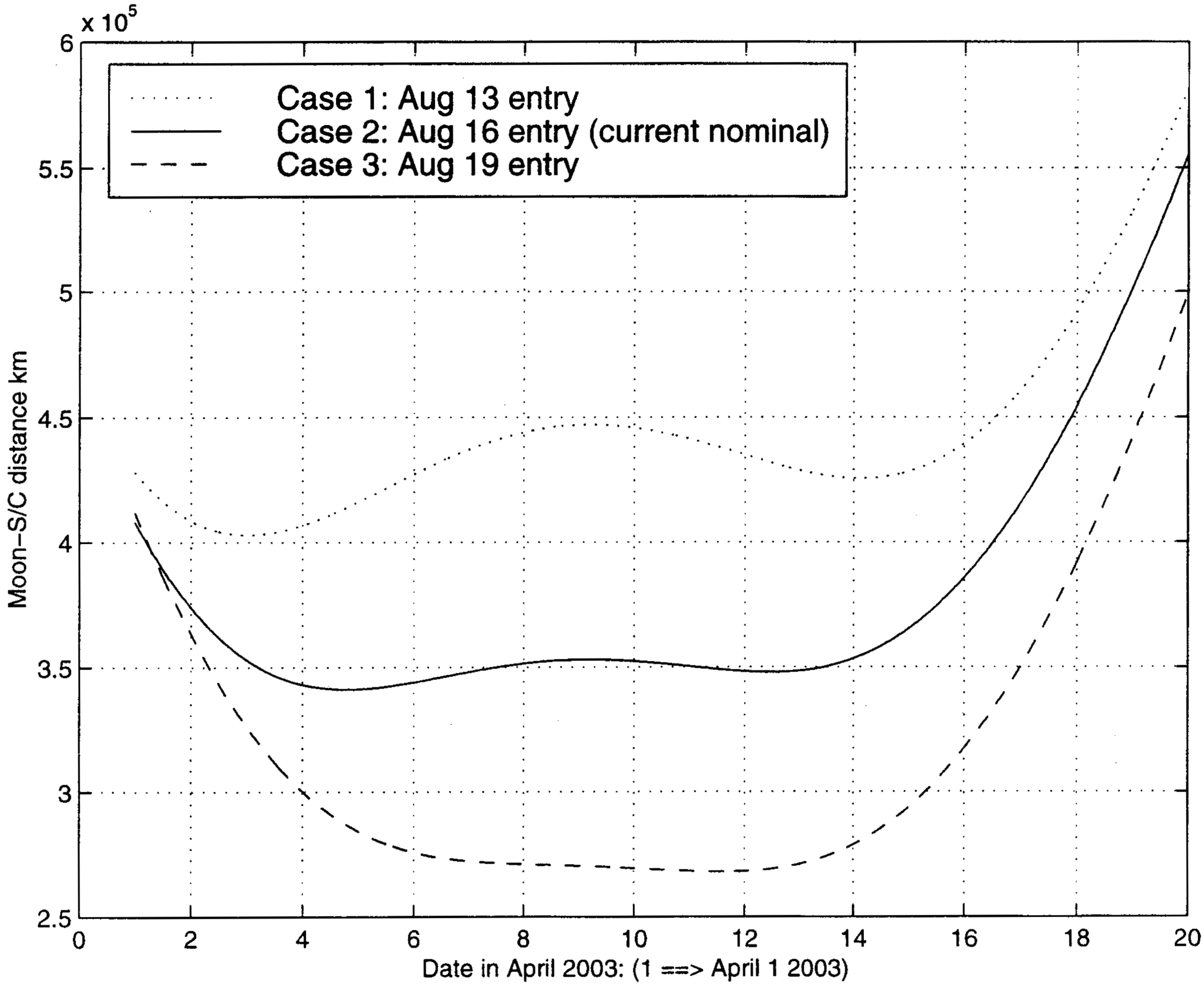

Figure 3. Moon−spacecraft distance on early part of return leg